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OVERVIEW OF HIGH PERFORMANCE AIRCRAFT PROPULSION

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This paper presents the basic overall scope of the Lewis High Performance Aircraft Propulsion Research and Technology effort. High performance fighter aircraft of interest include supersonic fighters with such capabilities as short take off and vertical landing (STOVL) and/or high maneuverability. The effort is primarily focused on component-level experimental and analytical research. This research is designed to provide databases for verification of design technology and for calibration of the CFD tools available for design use. Examples from each of the research areas are discussed, and a brief look at future directions for high performance aircraft research and technology is presented.

This is the High Performance Aircraft Propulsion Technology Section. High performance fighter aircraft of interest include supersonic fighters with such capabilities as short take off and vertical landing (STOVL) and/or high maneuverability. This figure indicates the basic overall scope of the Lewis high performance aircraft propulsion area. The effort is primarily focused on ground-based, component-level experimental and analytical research. The research is designed to provide experimental databases for technology verification and for identification and calibration of the CFD tools available for design use. It should be noted that the advanced light-weight and high-temperature materials being developed under the joint NASA/DOD IHPTET program are key to high performance aircraft propulsion systems, and they are critical to the long-term goals and success of this program. However, because these advanced materials have many applications, they are described in the Materials and Structures Section.

High Performance Aircraft

- Overview of High Performance Aircraft Propulsion
- Highlight Topics
  - Flow visualization and hot-gas ingestion characteristics of a vectored thrust STOVL concept
  - High angle-of-attack inlets

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The High Performance Aircraft Section consists of three papers: first, a general overview, which includes an overall summary of recent activities and a brief look at plans for the future; and then two papers, which highlight hot-gas ingestion and high angle-of-attack inlets. Hot-gas ingestion is a major problem for jet-lift-powered vertical landing fighter aircraft, and high angle-of-attack inlets are key to the new generation of high maneuverability fighters.

High Performance Aircraft Propulsion

- **Program Objective**

  Ready technology options for revolutionary new capabilities in future high performance aircraft

- **Program Approach**

  Validate and demonstrate enabling technologies for supersonic STOVL and high maneuverability as potential capabilities for future fighter/attack aircraft

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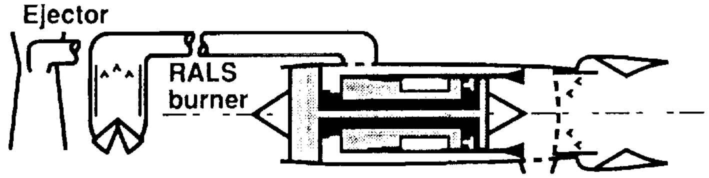
This figure states the overall objective of the High Performance Aircraft Propulsion Program, which is the development of the long-lead, high-risk, enabling technologies for these revolutionary aircraft. Specifically, the program will validate and demonstrate enabling technologies for supersonic short take-off/vertical landing (supersonic STOVL) and high maneuverability aircraft. Once validated, these technologies will become options available for Air Force and Navy consideration while the requirements for the next generation fighter are being developed. The program is being accomplished through joint studies and research with the United Kingdom (the US/UK ASTOVL Program), and with other NASA, Air Force, and Navy research organizations, including NASA Ames and NASA Langley, the Navy Propulsion Test Center, and the Air Force Wright Laboratory. However, the Air Force has recently discontinued its supersonic STOVL studies.

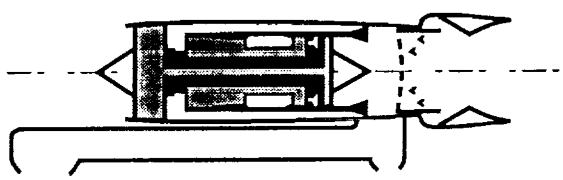
US/UK ASTOVL Studies

Propulsion Concepts
(Remote augmentors and mixed flows)

- Fan bleed systems



- Exhaust bleed (MFVT/REX)



Technology Needs:
- Diverter valve and ducts
- Hot-gas ingestion
- Integrated controls
- Nozzles
- STOVL augmentors

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Of major impact on our program was the US/UK ASTOVL Program joint study that considered four basic types of supersonic STOVL fighters (ref. 1). These included vectored thrust, ejector augmentor, remote augmentor, and tandem fan jet lift concepts. Although there are others, these four single-engine concepts were believed to represent the best alternatives for the studies. The study results defined the technologies that needed to be developed under the program. The figure above summarizes the specific technology needs of the propulsion system, as identified by the studies. Although the studies did not identify a specific propulsion concept for ASTOVL, they did identify the propulsion features that can lead to the best potential aircraft. The two main features are (1) remote augmentors, or lift jets, which allow greater aircraft design flexibility, and (2) mixed flow exhaust through a single rear nozzle, which permits somewhat better performance for up and away flight. The key propulsion technology needs for these systems include diverter valves and ducts, hot-gas ingestion alleviation and avoidance, integrated controls, vertical lift nozzles, and STOVL augmentors.

High Performance Aircraft Propulsion–Plan Matrix

Research Area		Supersonic STOVL		High Maneuverability	
		Experiment	Analysis	Experiment	Analysis
Hot-gas ingestion		√	√	N/A	
Ventral nozzles		√	√		
Off-takes, valves, and ducts		√	√		
Integrated flight/ propulsion controls		√		(STOVL effort applicable)	
Thrust augmenting ejectors		√	√	N/A	
Inlets	High alpha &short diffuser	(High maneuverability effort applicable)		√	√

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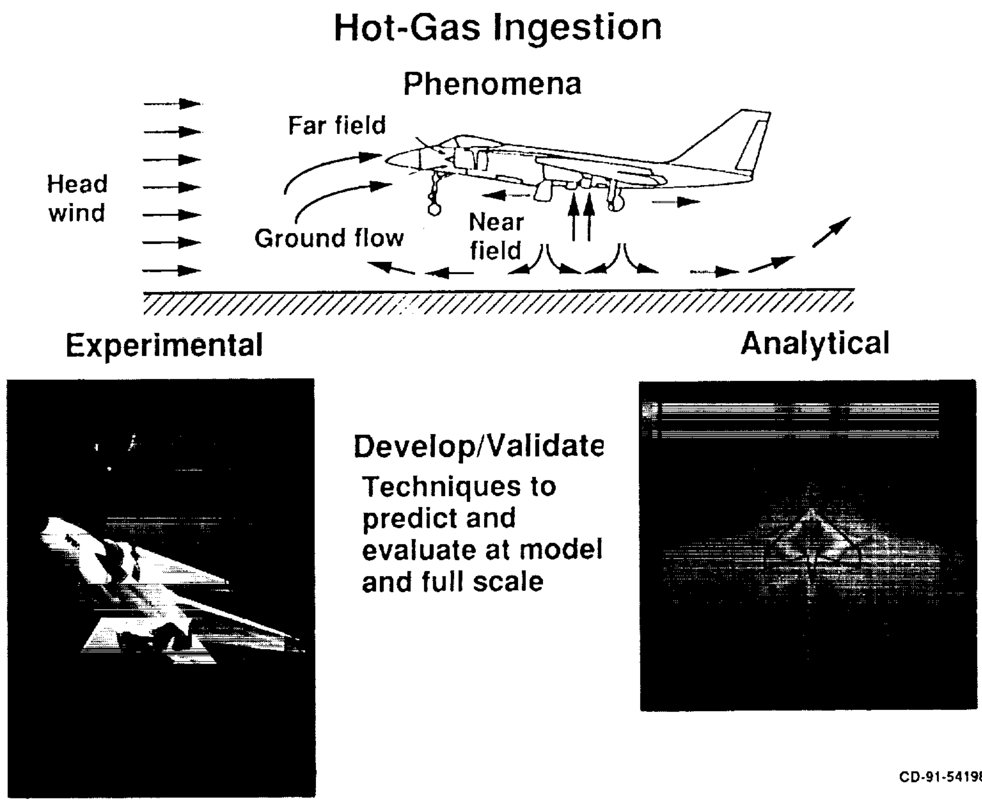
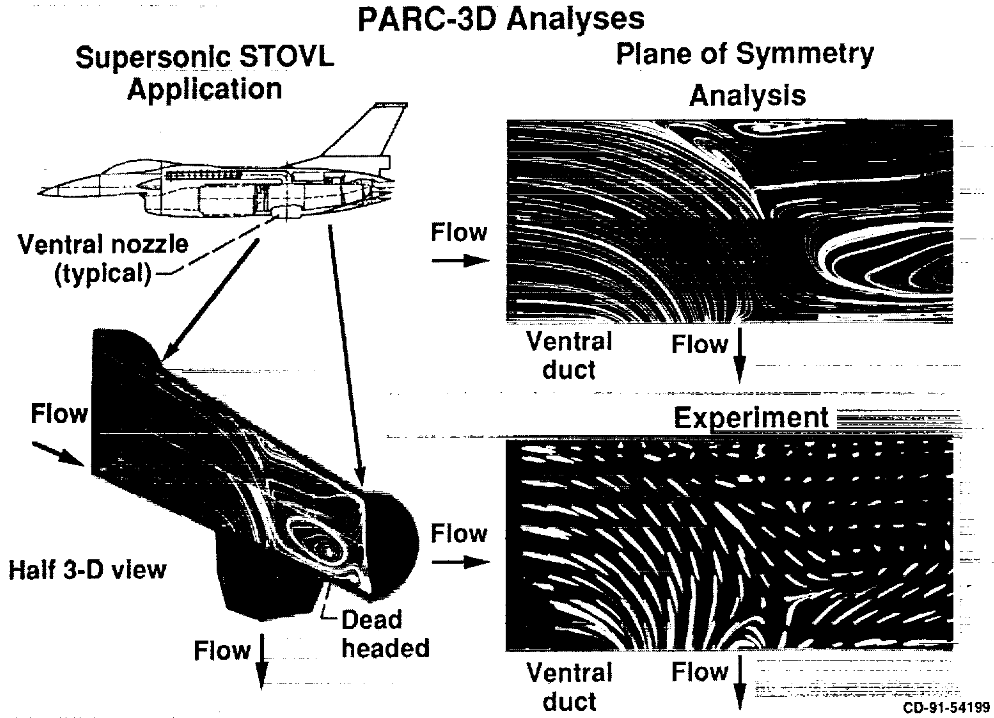
Because of the outcome of the US/UK ASTOVL study, the scope of the Lewis program includes the first five research areas listed in this figure. Inlet technologies have been added because they represent an essential technology need for high angle-of-attack/high maneuverability propulsion systems. Of the five supersonic STOVL technology efforts, we believe the integrated controls methodology is generally applicable to the high maneuver area as well. Also, even though the inlet effort is focused primarily on high angle-of-attack (high alpha) and diffuser boundary layer control, supersonic STOVL inlet systems will also require these technologies. In addition, the matrix emphasizes that each technology area includes both analytical and experimental research, except for controls, which is primarily analytical. The experimental research will provide data for verification of the analyses as well as databases of related information on performance and design requirements. The remainder of this report and the two that follow describe the status and summary results for each research area.



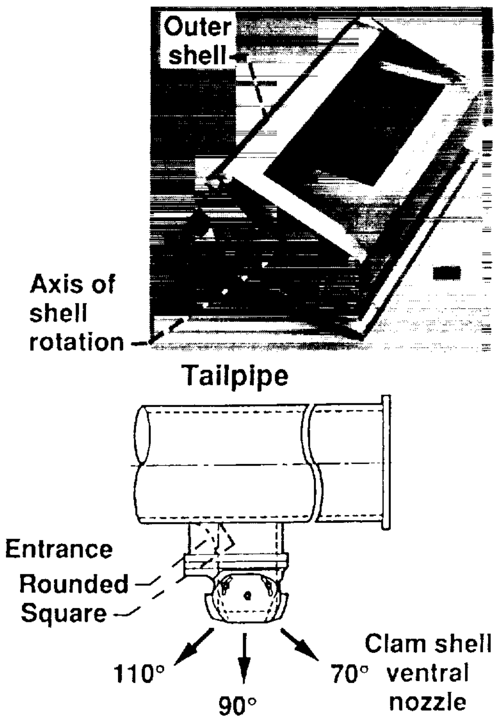
This figure will only introduce the subject of hot-gas ingestion. Hot-gas ingestion occurs when a lift-jet-powered aircraft approaches the ground; the jet exhaust hits the ground and either spreads out along the ground surface or is reflected back up to the underside of the aircraft. In the first case, the hot gas eventually rises or is blown back toward the aircraft where it can be ingested by the inlet and engine. In the second case, the hot gas flows around the fuselage and is ingested by the inlet. In either case this results in temperature distortion and loss of engine stability margin and/or performance. The objective of the hot-gas ingestion research at Lewis is to develop a database for use in studying the impact of hot-gas ingestion on engine performance and stability and for calibrating prediction techniques. Although configuration dependent, methods for controlling hot-gas ingestion have also been investigated. The paper that follows will present significant results of the experimental and analytical hot-gas ingestion research. The analytical effort is being accomplished by the Internal Fluid Mechanics Division. The lower right plot in the figure shows a computed ground plane temperature pattern that is representative of their work (ref. 2).

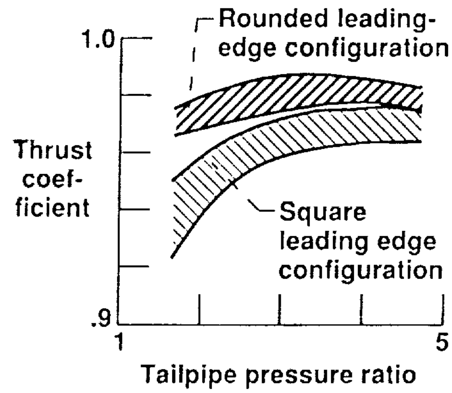
Ventral Nozzles



Ventral nozzles can provide vertical lift thrust behind the aircraft center of gravity during hover and low-speed operations. Their main advantage is that the thrust axis can be located closer to the center of gravity than can an aft deflecting nozzle, which allows greater aircraft design flexibility. The initial focus of the ventral nozzle research was to assess an available, full Navier-Stokes CFD code, PARC-3D, for predicting the details of the ventral nozzle internal flow field. The approach was to design a simple experiment that included the key flow physics, but was relatively easy to grid for the CFD analysis (ref. 3). In the lower left of the figure is a half section of this arrangement, with computed flow stream lines shown on the plane of symmetry. The tailpipe was modeled experimentally and analytically as a constant area duct terminated with a flat plate simulating a blocked main nozzle. The ventral nozzle was modeled as a two-dimensional convergent nozzle located at right angles to this main duct. Experimental paint streaks were obtained by using a flat plate installed on the plane of symmetry in the tailpipe duct. The right half of the figure directly compares the paint streaks and the analytical stream lines. Qualitatively, the results are very similar. Nozzle performance parameters such as mass flow, thrust, thrust angle, thrust coefficient, and flow coefficient were all predicted by PARC-3D (ref. 3) to better than 1 percent of the experimental values. The CFD analysis also identified a pair of vortices near the upstream surface and an accompanying large separation on the surface of the two-dimensional ventral nozzle duct. These disturbances caused the exit flow and thrust to be turned about 5° more than the mechanical angle of 90°. They also caused most of the approximately 5-percent pressure loss for the system.

Vectoring Ventral Nozzles





Effects of Ventral Entrance Geometry

Leading edge	Overturning, degrees
Square	5
Rounded	2

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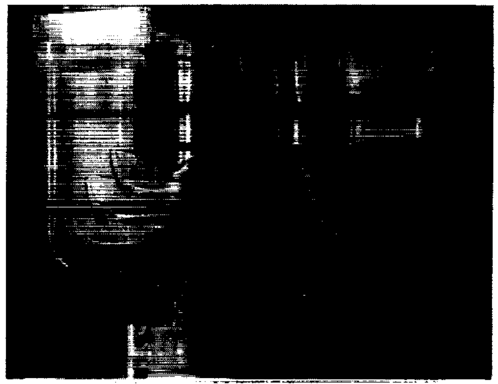
To assist transition between hover and wing-borne flight, a vectoring capability is desired in ventral nozzles. One possible method to provide thrust vectoring would be to implement a clam-shell type of two-dimensional convergent nozzle. The previously described ventral nozzle experiment was modified (ref. 4) to incorporate this technique. Whereas in a production design each of the outer shells could be independently actuated, for this experiment the exit area and the two outer shells were connected, but could be rotated ±20° from the vertical. A rounded entry to the ventral nozzle was also investigated to reduce the internal pressure losses due to the separations discussed on the previous figure. Results of this experiment are shown in the right half of the figure above. For the thrust coefficient, results are shown in bands rather than individual points because of the variation in thrust coefficient due to the vector angle. However, the main point to be made here is that the thrust coefficient can be improved with the simple aerodynamic rounding of the upstream entrance to the ventral nozzle. Also, the rounding reduces the overturning of the thrust vector from about 5° to about 2°. A CFD analysis of this configuration is not available, but we would expect the vortices and separations to be significantly reduced by this simple treatment.

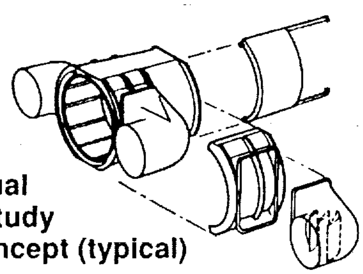
Off-Takes, Ducts, and Valves



Small-Scale Water Tank Experiment

Critical Technologies Needing Data

- Pressure losses/flow path
- Cooling/materials
- Transition control
- Sealing (leakage)
- Weight



Conceptual Design Study Valve Concept (typical)

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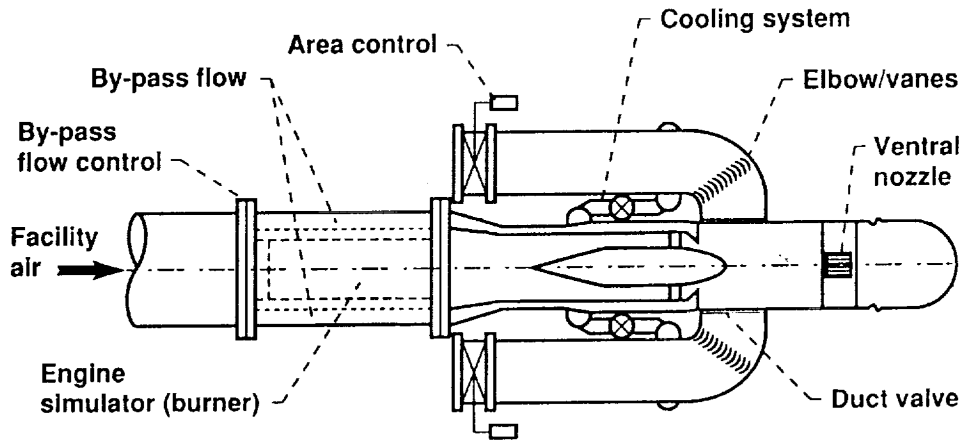
A relatively new research area, and key technology area for supersonic STOVL, is high performance and low loss exhaust gas off-takes and transport ducts that deliver the flow to the vertical thrusting systems. Recognizing a need for further study in this area, we contracted with Pratt & Whitney and McDonnell Aircraft to experimentally study basic flow phenomena in off-takes in a water tank. A laser light sheet was used to visualize the flow. Also, the bypass and core flows were independently controlled, as were the location of the mixing plane, flow splits, and so on. One of the configurations is shown in the upper left of the figure; in this case, mixing was not complete and the dark areas, which represent high-temperature gas, reach the outside off-take wall. Conceptual design studies of blockers and off-takes were also performed under contract by Pratt & Whitney. One of their conceptual designs is shown in the lower left of the figure. Based on the results of these two studies, the needed critical technologies and design databases were identified.

Hot-Flow Model Test Rig Concept



Variables

- Engine by-pass ratio
- Flow off-take configuration
- Cooling flows
- Duct/turning vane configuration
- Ventral nozzle size/location

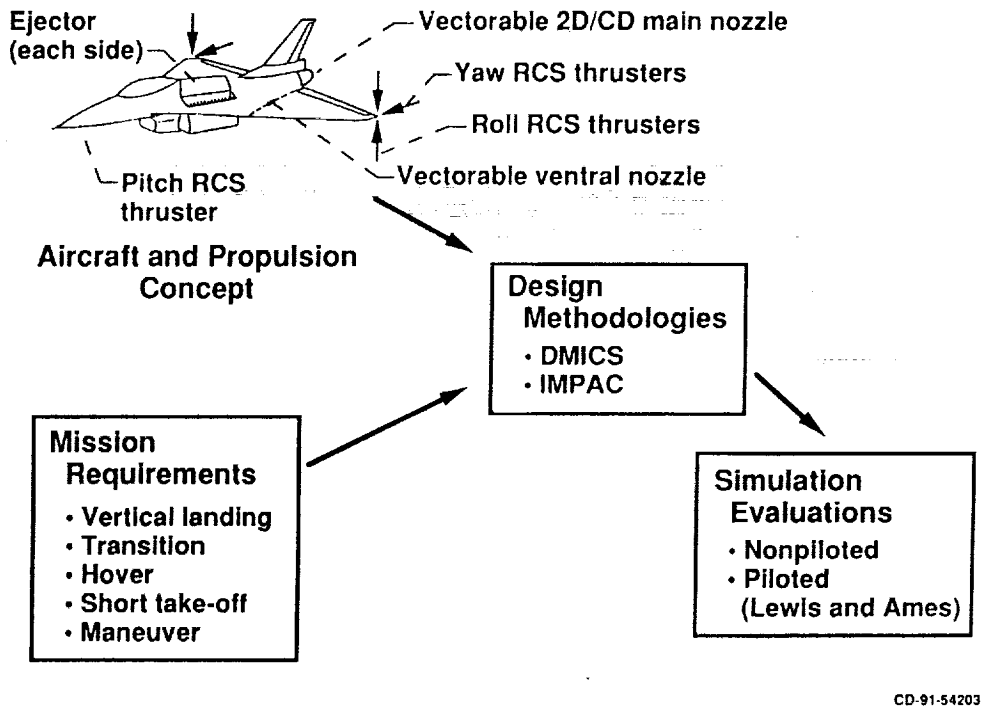
Typical Results

- Heat transfer data for cooling system design
- Flow pressure/temperature profiles
- Fan & core stream mixing
- Effect of nonsymmetric lift nozzle area variation

CD-91-54202

The results of the aforementioned conceptual design studies of valves and off-takes were expanded to define the requirements for an approximately half-scale, heated, dual-flow test rig. This rig, which will be used to develop the desired experimental database for valve and off-take designs, is shown here in conceptual form. A modification to the Lewis Powered Lift Facility is being made to incorporate a burner for simulating core engine exhaust gas and a mechanism for varying the bypass ratio (or flow split) of the heated and unheated streams. The test hardware will be of modular design so that different arrangements of off-takes and turning vanes as well as ventral nozzle locations can be investigated. Although we do not plan to use full temperatures (to save cost and lessen complexity), temperature differences will be sufficient to identify where cooling and/or high temperature materials are required. The Reynolds number will be approximately the same at the reduced temperature as that at full scale so that mixing effectiveness can be addressed. Basic performance data on pressure losses, flow coefficients, mixing, and such will be obtained. As stated before, the goal is to obtain data to establish design requirements or criteria, but flow data for calibration of analyses will also be obtained where possible.

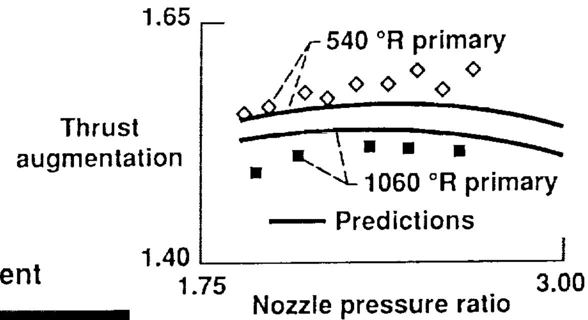
Integrated Flight-Propulsion Controls Approach



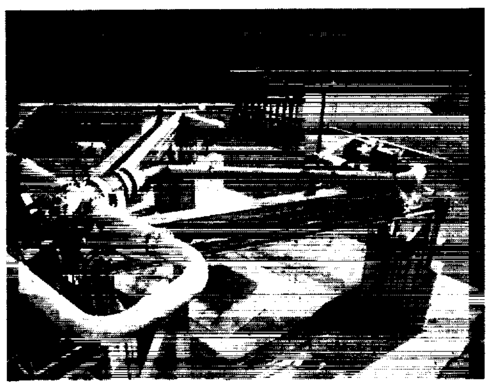
The approach and status of the ongoing integrated controls effort is presented in this figure. Integrated flight-propulsion control is critical to supersonic STOVL because the propulsion system performs essentially all of the flight control functions while the aircraft is in transition and hover. Lewis is focusing on developing and demonstrating an Integrated Flight Propulsion Control system design methodology. The Air Force Design Methods for Integrated Control Systems (DMICS) (refs. 5 and 6) is the basis for our contract study by General Electric, General Dynamics, and System Control Technology. In parallel, the Instrumentation and Controls Technology Division is investigating a new optimization approach called Integrated Methodology for Propulsion and Aircraft Control (IMPAC). The Lewis IMPAC approach uses the H-Infinity control synthesis technique (ref. 7). The goal of these methodologies is a validated design procedure for integrated control which performs a systematic, top-down design based on the mission requirements and the system to be integrated. Our approach is to apply the methodologies, simulate the resulting control logic in software, and evaluate the resulting integrated control logic on nonpiloted and piloted simulations, the latter jointly with NASA Ames. The DMICS approach is currently scheduled for piloted evaluation on Ames simulators in the spring of 1992. The IMPAC approach has been evaluated in a nonpiloted decelerating transition simulation.

Thrust Augmenting Ejectors Hot Primary Results

Performance Results



Full-Scale Ejector Augmentor Component



Summary

- Ejector type STOVL thrust augmentors demonstrated
- Desired performance levels achieved
- Design remains an art

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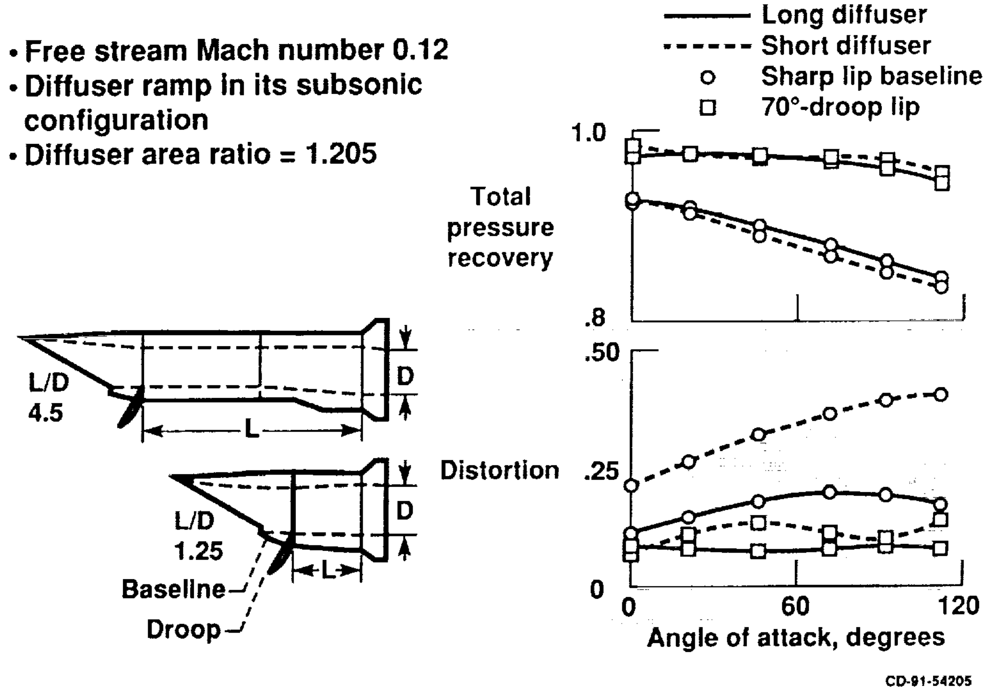
Recently, we have completed our experimental research with ejector augmentors. This research started as a joint effort with the Canadians and the de Havilland Aircraft Co. (ref. 8), but this Joint US/Canada Focused Ejector Program has been discontinued. However, Boeing/de Havilland has continued to support ejector research and has provided an ejector designed for the elevated primary gas temperatures expected in a mixed flow turbofan engine. The US/UK ASTOVL studies indicated the worth of such systems, and therefore the interest in a hot primary ejector has continued. This full-scale ejector is shown mounted in the Powered Lift Facility. Its internal physical dimensions are approximately 9 ft long by 3 ft wide at the primary nozzle exit. The curves plotted in the right of the figure summarize some of this recent testing and show predicted and measured performance at two primary nozzle gas temperatures. The predictions are based on a semiempirical code developed under contract by Sverdrup (ref. 9). Our conclusions about ejector type STOVL thrust augmentors are that, although they have been successfully demonstrated and the desired performance levels achieved, designing them remains an art. Even though we have completed our currently planned research on thrust augmenting ejector systems for supersonic STOVL, more work could be done. Specifically, ejector designs with primary nozzle pressure ratios representative of future advanced military engines need to be investigated, but this is not currently perceived as a high priority need.

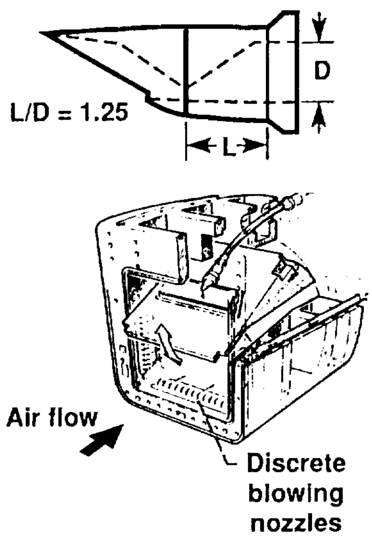
Effect of Subsonic Diffuser Length
2-D Supersonic Inlet

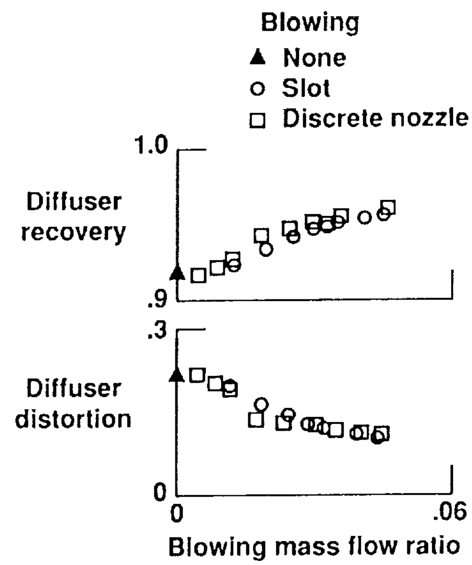


This section will cover one element of the inlet portion of the High Performance Aircraft Program - specifically, the results of the short diffuser experimental validation. An analysis performed in the early 1980's suggested that blowing could be used to avoid supersonic inlet diffuser separation. To test the concept, a previously designed and tested (ref. 10) Mach 2.2 two-dimensional inlet was modified. The inlet diffuser, which originally had a length-to-exit-diameter ratio of 4.5, was replaced by a diffuser of length-to-exit-diameter ratio of 1.25. Before the diffuser operation was assessed at simulated supersonic conditions, it was evaluated at subsonic conditions. Good quality flow must also be provided to the engine during low-speed operations and during maneuvers. Prior testing (ref. 10) investigated the angle-of-attack performance of the inlet-diffuser combination and looked at drooping the lower lip of the inlet to improve performance. This figure compares the performance of the long (baseline) and short diffuser model inlets, and a normal lip and a 70°-droop lip at free stream Mach 0.12 over an angle-of-attack range. At these conditions the pressure recovery for the short diffuser is comparable to the long diffuser. The 70°-droop lip provides considerable and comparable improvement for both inlets. In terms of distortion, however, the short diffuser does not do as well as the long diffuser, particularly for baseline sharp lower lip. The 70°-droop lip is, however, still very effective at improving distortion levels for the short diffuser inlet.

Effect of Blowing on Short Diffuser Performance
2-D Supersonic Inlet

- Diffuser ramp in supersonic configuration
- Diffuser area ratio = 1.915
- Throat Mach number = 0.77





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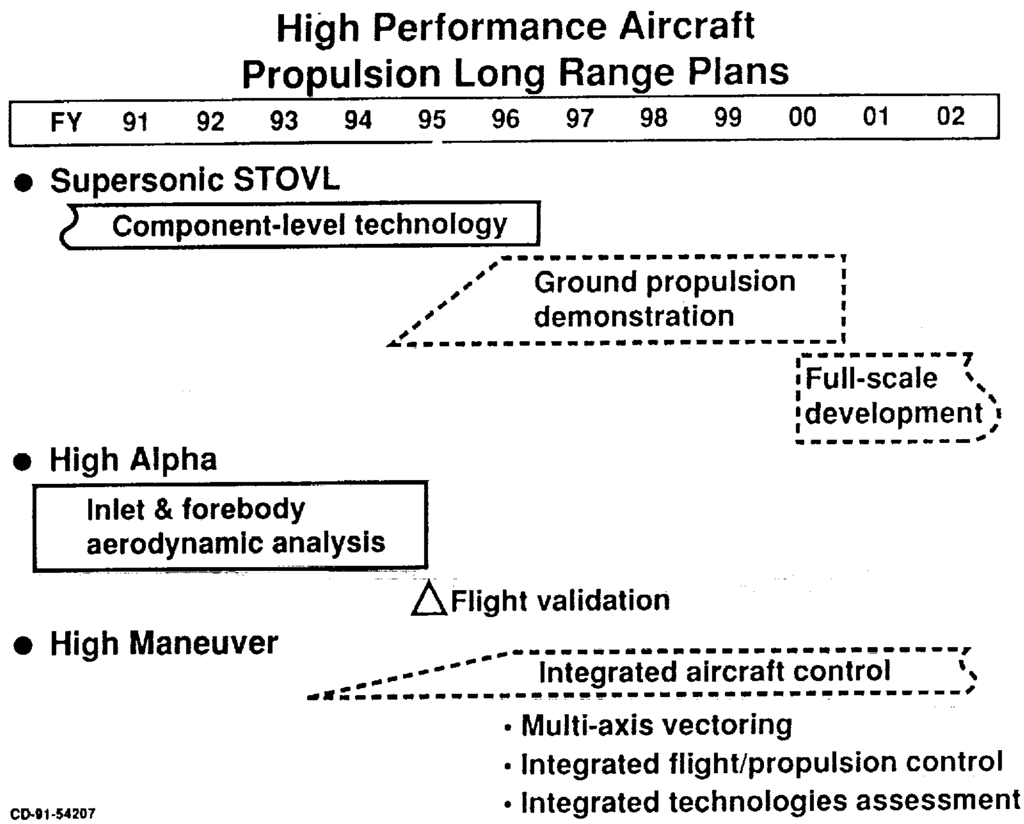
The previous figure did not address the diffuser separation issue for supersonic flight because the variable area diffuser was in its subsonic, or open, position. To simulate the effect of supersonic flow in a subsonic test, the inlet throat was closed to the nominal supersonic position, and the simulated inlet flow suction system was adjusted for a throat Mach number of 0.77; this resulted in approximately the same diffuser flow velocities as for the supersonic case. The flow in a diffuser with a length-to-exit-diameter ratio of 1.25 is guaranteed to separate from the diffuser walls. A "Panel Code" analysis (ref. 11) was used to predict diffuser separation and the amount of blowing required to avoid separation. The code predicted relatively low levels of blowing would be required to avoid such separations. In the lower left of the figure is a cut-away of the diffuser section. The discrete blowing nozzles (shown) or blowing slots were located just downstream of the inlet throat on all three fixed sides of the diffuser and the variable ramp. The plots on the right show the resultant inlet pressure recovery and distortion as a function of the blowing mass flow-to-inlet total flow ratio. The performance data for discrete nozzles and slots were essentially the same, and they approach those of the long diffuser. The experiment thus basically validated the prior analyses, and suggests blowing may offer appropriate solutions for certain types of diffuser performance problems.



This figure shows the overall NASA High Performance Aircraft Plan. The plan has three main elements: supersonic STOVL, high angle-of-attack (or alpha), and high maneuver technologies integration. Current plans call for continuation of the supersonic STOVL component-level technology development until an augmentation for a ground propulsion demonstration can be accomplished. We feel that such a demonstration is essential before supersonic STOVL can truly be considered available for aircraft development. This segment is shown by dashed lines in the figure because the funding and commitment to such an effort requires DOD participation in the program; this commitment is uncertain at this time. The current high-alpha forebody and inlet program continues to focus on flight and ground validation of advanced three-dimensional aerodynamics analyses and will culminate in flight experiments of the F-18 High Angle-of Attack Research Vehicle (HARV) with multi-axis thrust vectoring. The High Maneuver Integration area is proposed as a follow-on to integrate the various technologies evolving from the other programs. From the propulsion aspect, this will focus on multi-axis vectoring nozzles and integrated flight-propulsion control for the high maneuver flight regime.

Concluding Remarks

- Excellent progress on developing tools and understanding of key technology needs
- For hot gas ingestion, Lewis has developed unique capability and facility
- Internal 3-D Navier-Stokes codes are showing great promise for predicting flow inside complex geometries
- Ejector thrust augmentors provide desired levels of thrust when applied carefully
- As predicted by "Panel Codes," supersonic inlet diffuser boundary layer separation can be controlled
- Progress continues to be made; however there is still much work to be done

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In summary, for supersonic STOVL, excellent progress continues to be made in developing design tools and in better understanding the key technology needs. Further, as will be discussed in the following paper, NASA Lewis has a unique capability and facility for accomplishing hot-gas ingestion research. In all aspects of the program, internal three-dimensional Navier-Stokes flow codes are showing great promise for predicting aerodynamic performance inside complex geometries. Ejector thrust augmentors can provide desired levels of thrust when applied carefully. However, each application is unique. As predicted with "Panel Codes," supersonic inlet diffuser boundary layer separation can be controlled. Although we believe excellent progress is being made, there is still much work to be done.

REFERENCES

1. Levine, J.; and Inglis, M.: US/UK Advanced Short Takeoff and Vertical Landing Program (ASTOVL). AIAA Paper 89-2039, July 1989.

2. VanOverbeke, T.J.; and Holdeman, J.D.: A Numerical Study of the Hot Gas Environment Around a STOVL Aircraft in Ground Proximity. AIAA Paper 86-2882, July 1988 (Also, NASA TM-100895).

3. Smith, C.F.; and McArdle, J.G.: Analysis of Internal Flow in a Ventral Nozzle for STOVL Aircraft. AIAA Paper 90-1899, July 1990 (Also, NASA TM-103123).

4. Esker, B.S.; and McArdle, J.G.: Performance Characteristics of a One-Third-Scale, Vectorable Ventral Nozzle for SSTOVL Aircraft. AIAA Paper 90-2271, July 1990 (Also, NASA TM-103120).

5. Smith, K.L., et al.: Design Methods for Integrated Control Systems. AFWAL TR-86-2103, Wright Patterson AFB, OH, Dec. 1986.

6. Shaw, P.D., et al.: Design Methods for Integrated Controls Systems. AFWAL TR-88-2061, Wright Patterson AFB, OH, June 1988.

7. Garg, S., et al.: H-Infinity Based Integrated Flight/Propulsion Control Design for a STOVL Aircraft in Transition Flight. AIAA Paper 90-3335, Aug. 1990 (Also NASA TM-103198).

8. Corsiglia, V., et al.: Large-Scale Wind Tunnel Tests of an Ejector-Lift STOVL Aircraft Model: AIAA Paper 89-2905, July 1989.

9. Drummond, C.K.: A Control-Volume Method for Analysis of Unsteady Thrust Augmenting Ejector Flows. NASA CR-182203, 1988.

10. Mark J.L.; McGarry, M.A.; and Reagan, P.V.: Research on a Two-Dimensional Inlet for a Supersonic V/STOL Propulsion System. NASA CR-174945, 1984.

11. Hess, L.J.; and Friedman M.D.: Calculation of Compressible Flow in and About Three-Dimensional Inlets With and Without Auxiliary Inlets by a Higher-Order Panel Method. NASA CR-168009, 1982.